

not such close approximations to orifices in truly thin plates as to warrant the acceptance of this result without apparatus of more elaborate construction. Moreover, there is a possibility of slight leak in the grooves of the shutters, which ought not to be disregarded.

The observations are, however, sufficient to show that a properly constructed apparatus is capable of making measurements of the effective areas of orifices with a very considerable degree of precision. It is well known that if the orifice be not an aperture in a thin plate, but in the form of a tube, straight or bent, the flow through the orifice can be represented by an equation of the same form as if the orifice were a thin plate aperture, viz. :—

$$H = RV^2,$$

but in the case of a more complicated orifice R cannot be so easily calculated from the dimensions; the value of R might, however, be determined experimentally for an orifice of any shape and dimensions by a pneumatic bridge of suitable size, and the result might be expressed, as M. Murgue suggests for the case of mines in the work already referred to, by stating the area of the thin plate orifice to which the given orifice is equivalent. The comparison of calculated values of R with observed values obtained by a pneumatic bridge would enable us to determine a number of pneumatic constants that are at present only comparatively roughly ascertained, such, for instance, as the coefficient of air friction in tubes of different diameters, the constants of different forms of orifice, the effect of bends and elbows in pipes, and of gauze or gratings covering an orifice. And it would not, I think, be difficult to arrange the apparatus in such a way as to determine the law of resistance of a disc to the passage of air and its variation with velocity. The velocity can be increased to any extent that may be necessary by using a centrifugal fan to produce the head instead of the gas burner.

I am intending, if possible, to have my present apparatus altered in some of its details, so that the orifices may be more definitely expressed in terms of thin plate apertures, and then to use it for the determination of some of the pneumatic constants I have referred to.

II. "On the Effect of Tension upon Magnetic Changes of Length in Wires of Iron, Nickel, and Cobalt." By SHELFORD BIDWELL, M.A., F.R.S. Received April 8, 1890.

Preliminary.

A former communication to the Royal Society ('Roy. Soc. Proc.', No. 243, 1886, p. 257) contains an account of some experiments relating to the magnetic extensions and contractions of iron wires

under tension. Wires of several different sizes and qualities were suspended inside a magnetising coil, and were loaded with various weights; and in each case observations were made of (1) the smallest magnetising current which caused sensible change of length; (2) the current producing maximum elongation (if any) and the value of such elongation; (3) the critical current which was without effect upon the length of the wire; and (4) the contraction produced by a certain strong current.

The results indicated that the maximum elongation became smaller as the load was increased, disappearing altogether when the tension exceeded a certain limit; and that contraction began to take place at a correspondingly earlier stage in the magnetisation.

These results were chiefly of interest as disproving Joule's conjecture, which has often been quoted as if it were an experimental fact, that, under certain critical tension (differing for different specimens of iron, but independent of the magnetising force*), magnetisation would produce no change whatever in the length of the wire.

The subject, however, seemed worthy of more complete investigation, and I have lately undertaken a series of experiments in which the changes of length undergone by a stretched iron wire were traced continuously as the magnetising force was gradually increased from a small value up to about 375 C.G.S. units. Similar experiments were also made with a nickel wire and with a thin strip of cobalt, the behaviour of these metals under tension never having been previously studied.

Apparatus.

The apparatus employed was the one described and figured in my former paper. The diagram there given, together with a short description, is, for convenience, here reproduced (see fig. 1).

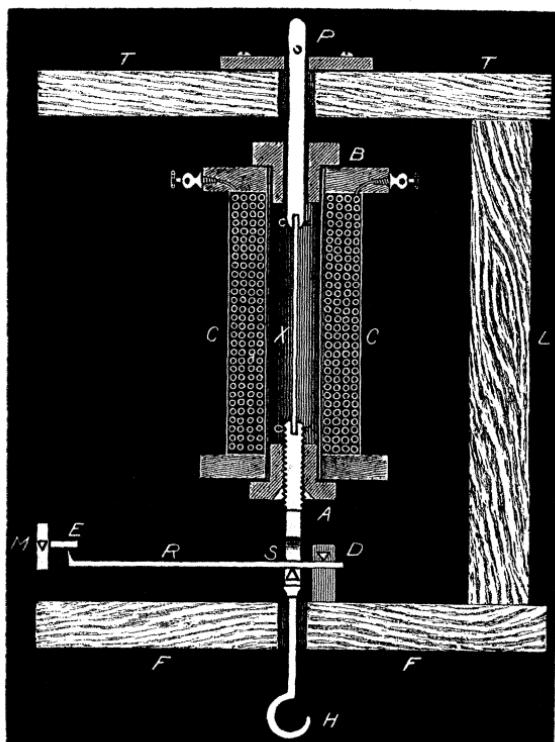
Experiments.

For reasons which need not be repeated here, it was found necessary to support the magnetising coil in the manner shown in the figure, its whole weight being borne by the experimental wire. The minimum load on the wire was therefore represented by the weight of the coil, together with the pull of the lever, the two amounting to 1.36 kilo. Greater tension was produced by attaching weights to the hook H.

The iron used was a piece of soft annealed wire, 0.7 mm. in diameter and 10 cm. in length, between the clamps. The weights

* At least within the limits of the forces employed by Joule, estimated to range from 7 to 114 C.G.S. units. See 'Roy. Soc. Proc.,' No. 242, 1886, p. 112.

FIG. 1.



The magnetising coil, CC, is supported by a stopper, A, which is inserted into the bottom of the coil. Through an axial hole in A is screwed a brass rod, terminating in a stirrup, S, beneath which is fixed a hook, H, for the suspension of weights. A second brass rod, suspended by a pin at P, passes freely through a stopper, B. The wire under experiment, X, is clamped between the ends of the brass rods. The knife-edge at the bottom of the stirrup acts upon a brass lever, R, one edge of which turns upon the knife-edge D, the other actuating a short arm, E, attached perpendicularly to the back of the mirror M. The mirror turns upon knife-edges about its horizontal diameter. By means of a lantern the image of a fine wire is, after reflection from the mirror, projected upon a distant vertical scale and serves as an index. Dimensions:—SD = 10 mm., DE = 170 mm., ME = 7 mm., distance from mirror to scale = 4706 mm., each scale division = 0·64 mm., length of X = 100 mm.

successively attached to it were equivalent to 1950, 1600, 1170, 819, 585, and 351 kilos. per square cm. of section.

The nickel wire was 100 mm. long, and 0·65 mm. in diameter; it was supplied by Messrs. Johnson and Matthey. The loads under which it was examined were 2310, 1890, 1400, 980, 700, and 420 kilos. per sq. cm.

The cobalt used was a narrow strip measuring 100 mm. by 2·6 mm. by 0·7 mm.; its cross section being, therefore, 1·82 sq. mm. It was not possible to obtain this metal in the form of a wire; and for the piece of thin rolled sheet from which the strip above-described was formed, I am indebted to the kindness of Messrs. Henry Wiggin and Co., of Birmingham, who had it specially prepared for me. The loads employed for the cobalt strip were equivalent to 772, 344, and 75 kilos. per sq. cm. The first of these was represented by an actual weight of 31 lbs.,* which was as great as the apparatus seemed capable of bearing without risk of injury.

In all the experiments the loads were successively applied in decreasing order of magnitude, and before every single observation the wire or strip was demagnetised by reversals, without, of course, being removed from the coil.†

The results obtained for iron are given in Table I, and also shown in the curves in fig. 2.

Those for nickel are given in Tables II and III, and in figs. 3 and 4. In fig. 3 the curve for 700 kilos. is represented by a dotted line for the sake of distinctness. Table III and fig. 4 are constructed from data obtained from a complete set of curves, like those in fig. 3; they show the magnetic contractions that would occur under increasing loads in constant magnetic fields of 125, 185, and 360 C.G.S. units respectively. These magnetic contractions would, of course, be superposed upon elongations of a purely mechanical nature, due to the tensional stress.

The results for cobalt are contained in Table IV and fig. 5. In the figure the contractions corresponding to the various loads are indicated by different kinds of marks, and a single curve has been drawn as smoothly as possible through the whole of them.

In all the tables and figures magnetic fields (which are those due to the coil alone) are given in C.G.S. units, and increments and decrements of length are expressed in ten-millionths of the length (10 cm., or about 4 inches) of the experimental wire or strip. In figs. 2 and 5, therefore, the height of each little square corresponds to 1/10,000 mm., or 1/250,000 inch, and in figs. 3 and 4 to 1/2,000 mm. or 1/50,000 inch.

* 14 kilos.

† The apparatus used for this purpose is described in 'Phil. Trans.', vol. 179 (1888), A, p. 206.

Table I.—Iron.

Magnetic field in C.G.S. units.	Elongations in ten-millionths of length with loads per sq. cm. of					
	351 kilos.	585 kilos.	819 kilos.	1170 kilos.	1600 kilos.	1950 kilos.
7	2	2	0	0	0	0
9	..	..	1.5	0	0	0
11	6.5	8	..	0	0	0
16	14	12	8.5	2	-1	-2
22	20	18	11.5	2.5	-2	-2.5
35	27	23	14.5	3.5	-3	-4.5
50	26.5	23	13	2		
88	25	19	9	0	-9	-13
138	17	10	2	-7	-17	-24
188	10.5	3.5	-3	-13.5	-23	-32
281	0	-9	-18	-24.5	-37	-48
375	-9.5	-21	-28	-39	-52	-62

Table II.—Nickel.

Magnetic field in C.G.S. units.	Contractions in ten-millionths of length with loads per sq. cm. of					
	420 kilos.	700 kilos.	980 kilos.	1400 kilos.	1890 kilos.	2310 kilos.
13	2	2	2	0	0	0
16	4	3	2	0	0	0
19	12	5	4	0	0	0
28	30	9	8	1	2	0
34	43	22	15	2	3	2
50	69	40	27	4	5	2
69	..	..	..	15	8	
72	102	65	53			
84	..	..	..	..	..	7
88	123	96	73	26	12	
103	142	123	98	43	21	13
125	162	156	122	56	30	17
159	190	193	165	88	52	32
184	209	221	195	109	..	43
188	..	..	..	..	68	
219	232	245	237	152	..	60
225	..	..	..	..	94	
275	256	275	284	194	..	91
284	..	..	..	..	127	
359	..	315	334	242		
363	288	..	..	..	..	140
384	..	..	..	..	176	

FIG. 2.

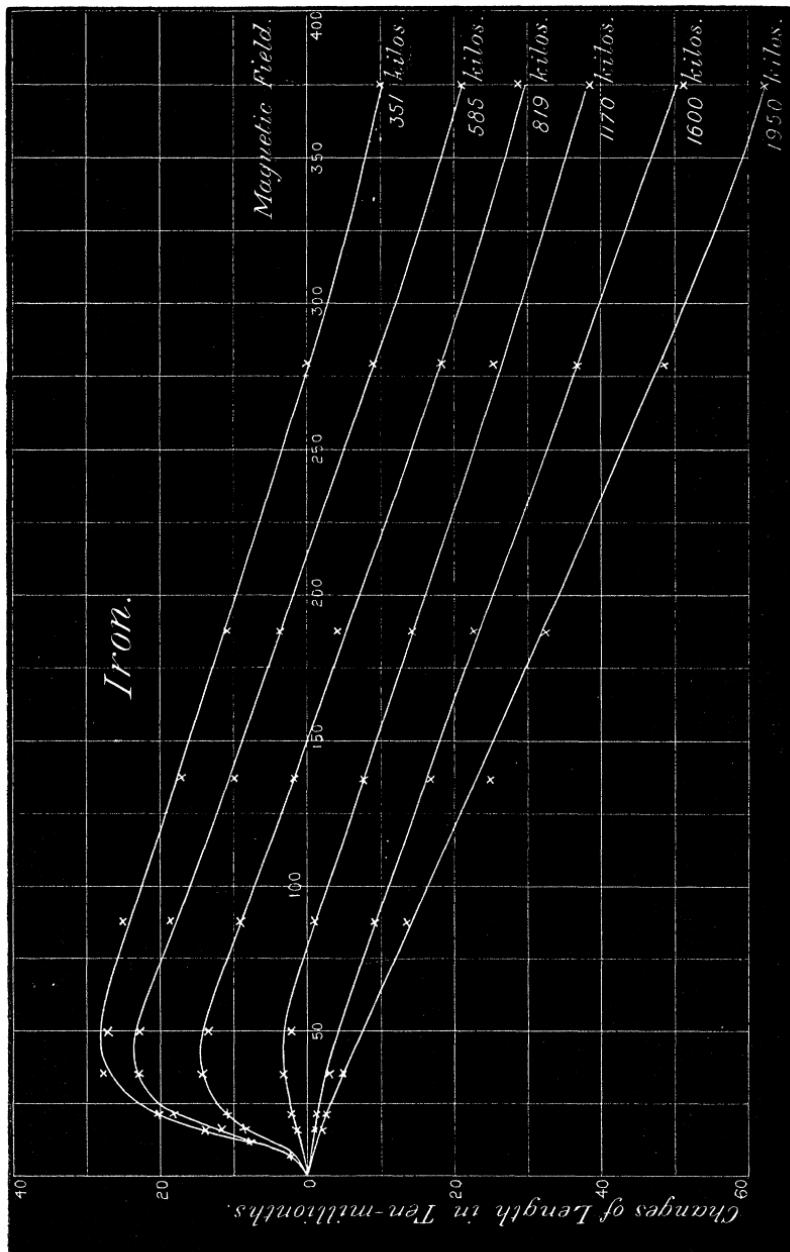


FIG. 3.

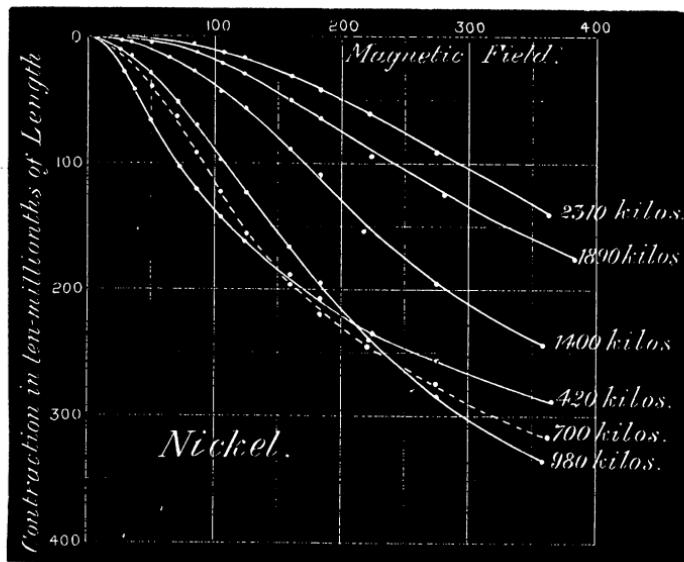


FIG. 4.

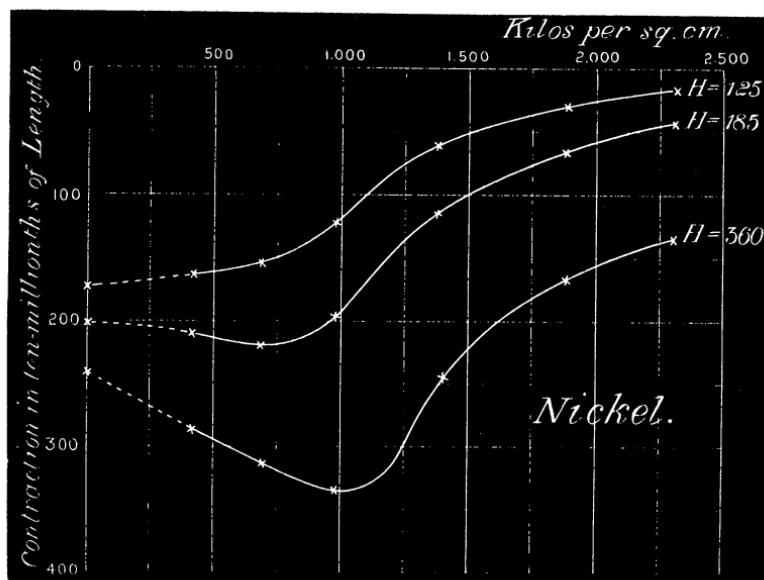
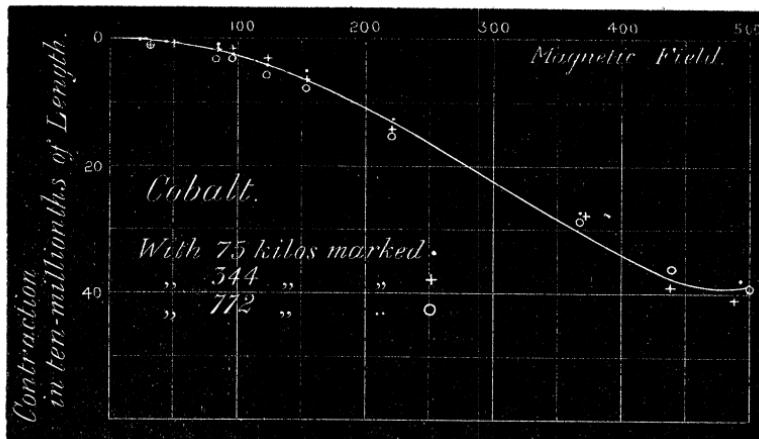


Table III.—Nickel.

Load in kilos. per sq. cm.	Contractions in ten-millionths of length in fields of		
	125 units.	185 units.	360 units.
0	172	200	242
420	162	209	287
700	156	221	315
980	122	195	334
1490	56	109	242
1890	30	66	165
2310	17	43	136

Table IV.—Cobalt.

Magnetic field in C.G.S. units.	Contractions in ten-millionths of length with loads per sq. cm. of		
	75 kilos.	344 kilos.	772 kilos.
22	0	0	0
34	0.5	0.5	0.5
47	0.5	..	0.5
50	..	0.5	..
84	1.5	2	3.5
98	3	2	3.5
125	4.5	3.5	6
156	6	7	10
219	13	15	15.5
369	28	28	29
438	38.5	39	36
490	..	41	
493	38	..	
500	..	..	39.5



Discussion of the Tables and Curves.

Iron.—The curves in fig. 2 clearly show the effect of tension in diminishing the maximum elongation and hastening the contraction. With the two greatest loads used there was no preliminary elongation at all. The curve for an unstretched iron rod is generally found to cut the axis at about 300; probably, therefore, if the wire used in these experiments could have been tested with no load, its curve would lie a little above that for the load of 351 kilos.

Nickel.—The results for nickel are of great interest. In fields below about 140 units increase of load is always accompanied by decrease of magnetic contraction, the earlier portions of the six curves in fig. 3 following one another in inverse order of the magnitude of the several loads. But, although the initial slope of the curves diminishes with increasing loads, the “turning points,” where the ratio of the contraction to the magnetic field is a maximum, occur later with great than with small loads, so that in a field of 360 the order of the relative values of the contractions for the three smallest loads is actually reversed, the contraction being greatest with the heaviest load and least with the lightest. It appears probable that, if the experiment had been carried far enough, the curve for 1400 kilos. would have crossed one if not all of the three curves lying below it. Whether the two remaining curves for 1890 and 2310 kilos. would behave similarly is more doubtful. Possibly they would have become parallel to the horizontal axis before the others were reached.

I think it may fairly be assumed that if the experiment could have been made with the wire quite unstretched, we should have obtained a curve having a steeper initial slope than any of those in the

diagram, but also reaching its turning point sooner, and therefore intersecting at least three or four of the others. Such an assumption is confirmed by some results obtained with a nickel rod 0.3 cm. in diameter, which have been given in a former communication,* and are reproduced in Table V.

Table V.—Unstretched Nickel Rod.

Magnetic field in C.G.S. units.	Contractions in ten-millionths of length.
65	104
125	167
181	199
237	218
293	233
343	240
393	242

A curve plotted from this table will be found to begin its descent between the curve for 420 kilos. and the vertical axis, and after crossing the others to intersect that for 1400 kilos. at $H = 355$. But of course experiments made with two different specimens of nickel are not strictly comparable.

In fig. 4 the results for nickel are presented in a somewhat different form, the curves showing the magnetic contractions of the wire under various loads in certain constant fields. The values for no load are taken from Table V, and the portions of the curves which depend upon the accuracy of these values are distinguished by dotted lines. It will be seen, however, that these portions are not of much importance.

From these curves we at once see that in a field of 125 units, increase of load always causes decrease of magnetic contraction. In a field of 185, magnetic contraction increases as the load is raised from nothing up to about 700 kilos. per square cm., again decreasing with greater loads. And in a field of 360 units this singular reversal is exhibited in a still more marked degree, the maximum magnetic contraction occurring with a load of about 950 kilos. per square cm.

The reversal phenomena observed in connexion with the magnetic contraction of nickel are strikingly analogous to those which occur in the magnetisation of a stretched iron wire, and which are commonly associated with the name of Villari.†

* 'Phil. Trans.,' A, 1888, p. 228.

† Poggendorff's 'Annalen,' 1868. See also 'Encycl. Britann.,' 9th edit., vol. 15, p. 269. When an iron wire subject to a magnetising force in the direction of its length is stretched by a certain force, the magnetisation of the wire is increased or diminished according as the magnetising force is less or greater than a certain critical value

Professor J. J. Thomson has shown* that the Villari effect is dynamically connected with the changes of length undergone by an iron rod when magnetised, an iron rod being lengthened in a weak magnetic field and shortened in a strong one. Now cobalt behaves oppositely to iron in this respect, a rod of cobalt becoming shorter in a weak field, longer in a strong one.† Professor Thomson, therefore, predicted that a Villari reversal would be found to occur in cobalt and that it would be of the opposite character to that in iron. Some experiments made by Mr. Chree‡ with a cobalt rod under pressure gave results in accordance with Professor Thomson's expectation.

But no reversal of the effect of magnetisation in diminishing the length of an unstretched nickel rod, has ever been observed. Such a rod always becomes shorter in a magnetic field, whether strong or weak. It appears to attain its shortest length in a field of about 750 units, but it does not pass a minimum, and become longer again in stronger fields, like cobalt. Applying Professor Thomson's reasoning, therefore, to the case of nickel, we should expect that it would be found not to exhibit any Villari reversal, either of the nature of that in iron, or of that in cobalt. Both Sir William Thomson and Professor Ewing have in fact looked for one and failed to find it. But in a paper read at the meeting of the Physical Society, on 21st March, 1890,§ Mr. Herbert Tomlinson gave an account of some experiments which, as he believed, showed that a Villari critical point really existed in nickel, though it was only to be reached by the application of comparatively great magnetising forces. If Mr. Tomlinson is right, I venture to suggest that his results may possibly be brought into harmony with Professor J. J. Thomson's mathematics by consideration of the experiments described in the present paper: for, as I understand Professor Thomson's argument, he has hitherto taken no account of the effects of mechanical stress upon magnetic changes of length.

Cobalt.—The results for cobalt show that the changes of length which this metal undergoes when magnetised are almost, if not entirely, unaffected by tensional stress, at least within the limits of the experiments. Having regard to the very marked influence of tension upon iron and nickel, this cannot but be regarded as a most remarkable fact.

(depending upon the magnitude of the stretching force) for which stretching produces no effect.

* 'Applications of Dynamics to Physics and Chemistry,' p. 54.

† 'Phil. Trans.,' A, 1888, p. 227.

‡ *Supra*, p. 41.

§ Not yet published.

Summary of Results.

Iron.—Tension diminishes the magnetic elongation of iron, and causes contraction to take place with a smaller magnetising force.

Nickel.—In weak fields the magnetic contraction of nickel is diminished by tension. In fields of more than 140 or 150 units, the magnetic contraction is increased by tensional stress up to a certain critical value, depending upon the strength of the field, and diminished by greater tension.

Cobalt.—The magnetic contraction of cobalt is (for magnetic fields up to 500 C.G.S. units and loads up to 772 kilos. per sq. cm.) practically unaffected by tension.

III. "On the Heat of the Moon and Stars." By C. V. Boys, A.R.S.M., F.R.S., Assistant Professor of Physics, Normal School of Science and Royal School of Mines, London. Received April 14, 1890.

Soon after I had completed the radio-micrometer and shown its great superiority over any form of thermopile and galvanometer, I was naturally anxious to carry out some research which would clearly demonstrate the capabilities of the instrument. The determination of the heating powers of the stars seemed most promising, for Dr. Huggins had, in 1869,* made experiments on the heating powers of some of the stars which, though they did not conclusively show that a thermopile was capable of measuring so minute a radiation, yet made it exceedingly probable that the effects observed, if not very exact in quantity, were at any rate real. Dr. Huggins, however, described his experiments and formed his conclusions with the utmost caution. A year later Mr. Stone described experiments which he had made with the great equatorial at Greenwich.† He at first used small thermopiles, but soon found, as we should expect, that a single pair was more sensitive to radiation brought to a point than a pile of many pairs. In attempting to obtain great sensibility by giving the galvanometer a long period he found it almost impossible to use the apparatus on stars at night. Every slight change in the sky, even though quite invisible to the eye, so disturbed the galvanometer that it was impossible to distinguish effects due to the stars from those caused by the varying clearness of the sky. Mr. Stone largely obviated this difficulty by placing in the focal plane of the object glass a couple of thermo-electric pairs so connected that a heating of the exposed face of one would produce an effect opposite

* 'Roy. Soc. Proc.,' vol. 17, p. 309.

† *Ibid.*, vol. 18, p. 159.

FIG. 1.

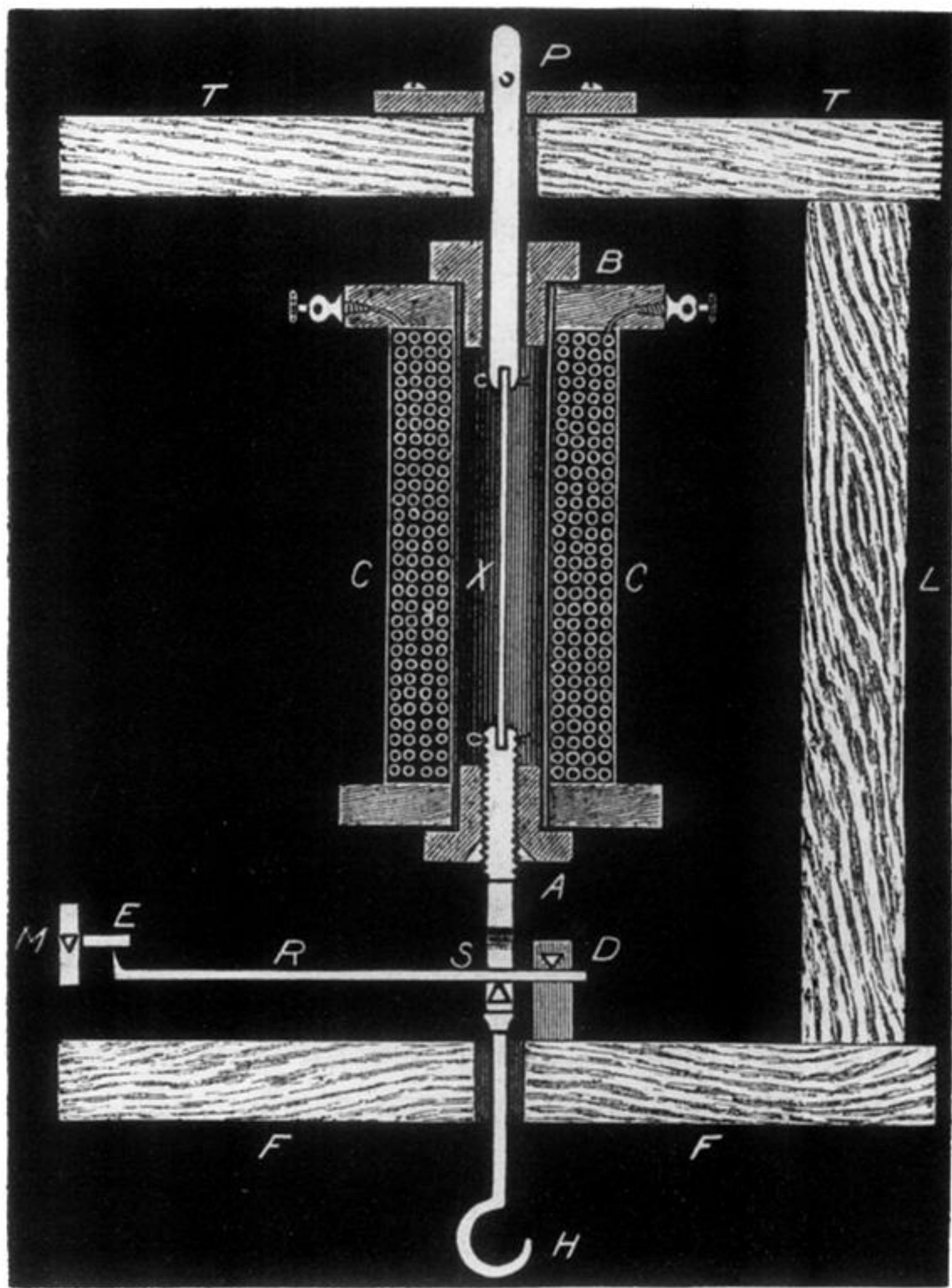


FIG. 2.

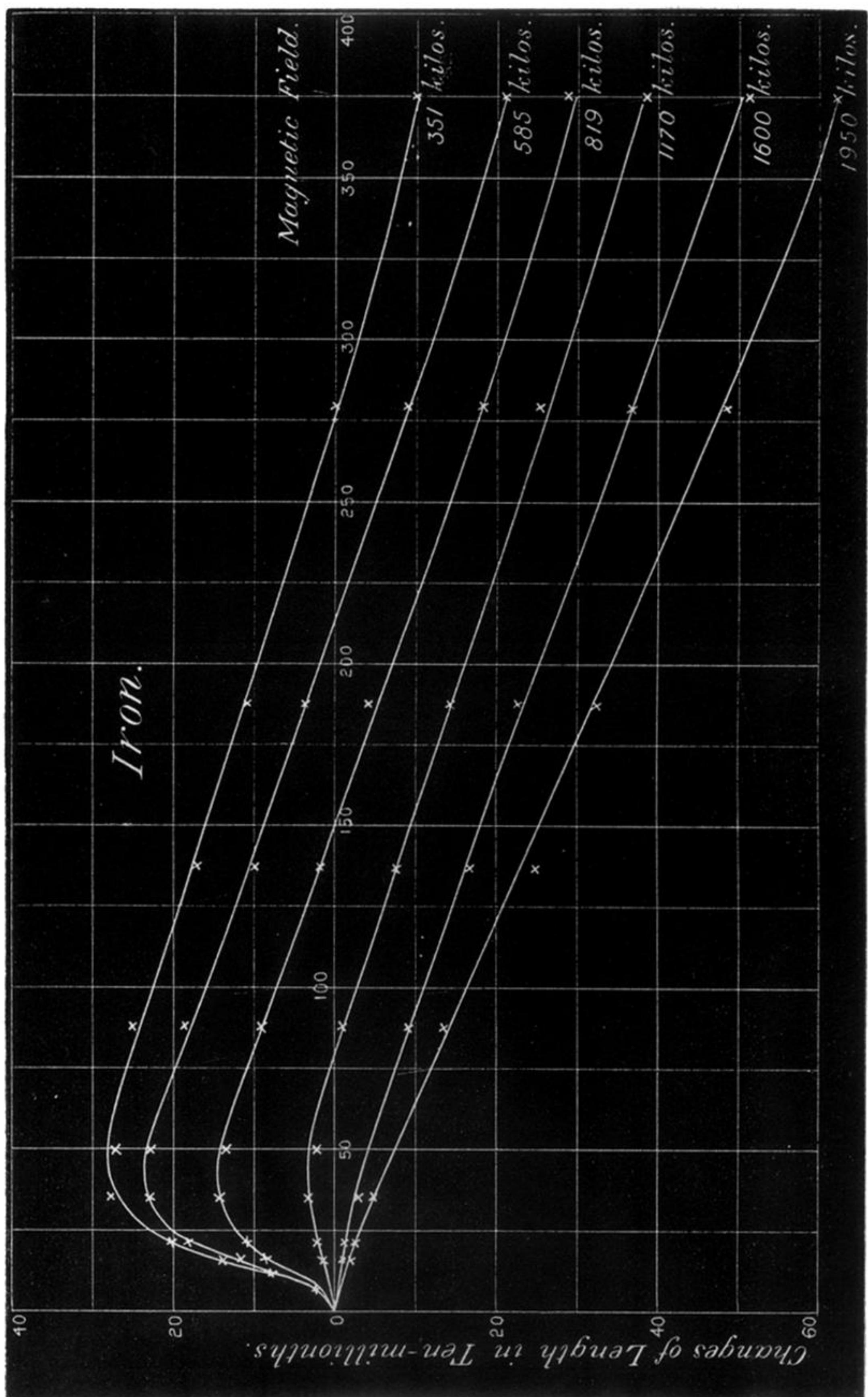


FIG. 3.

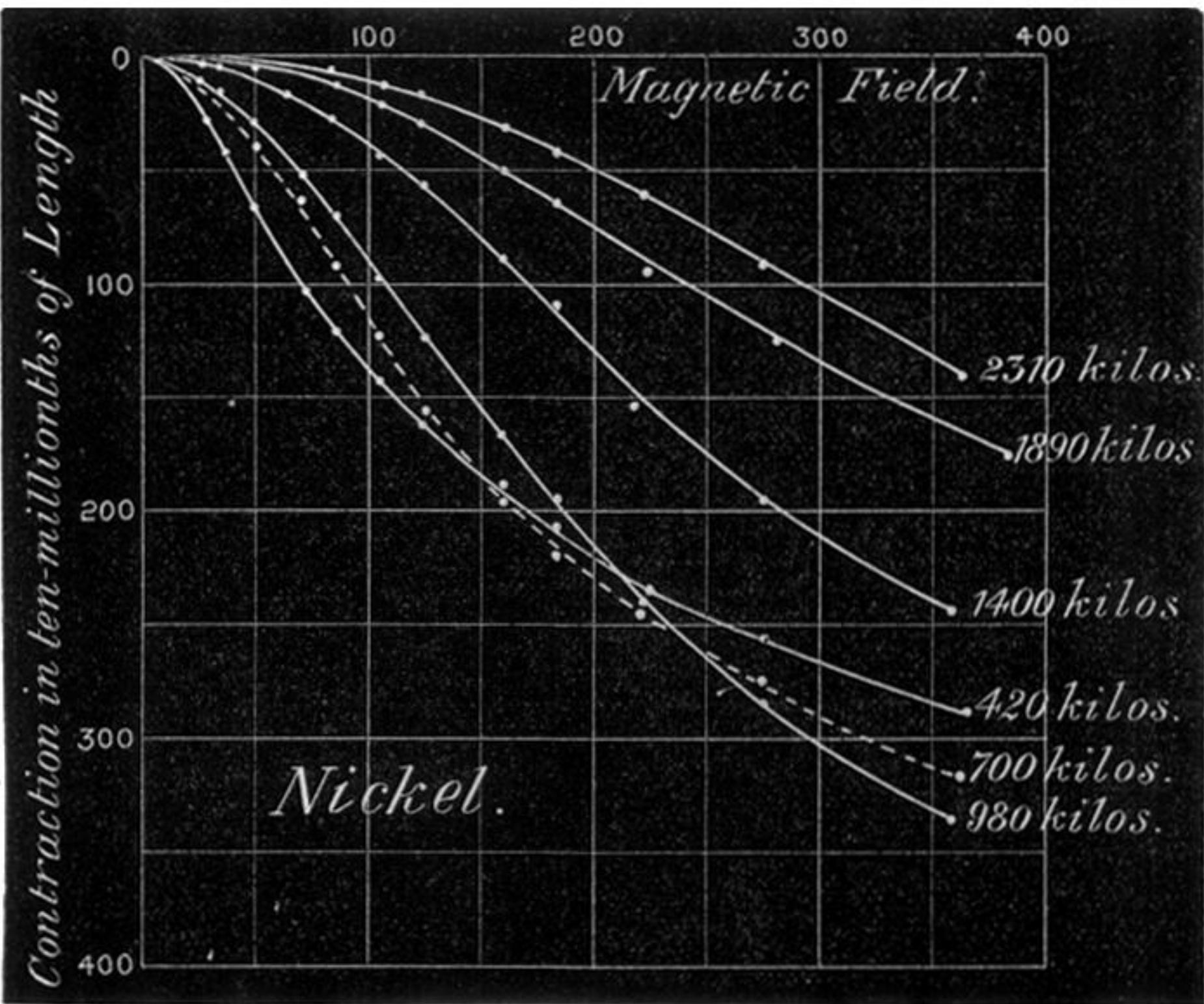
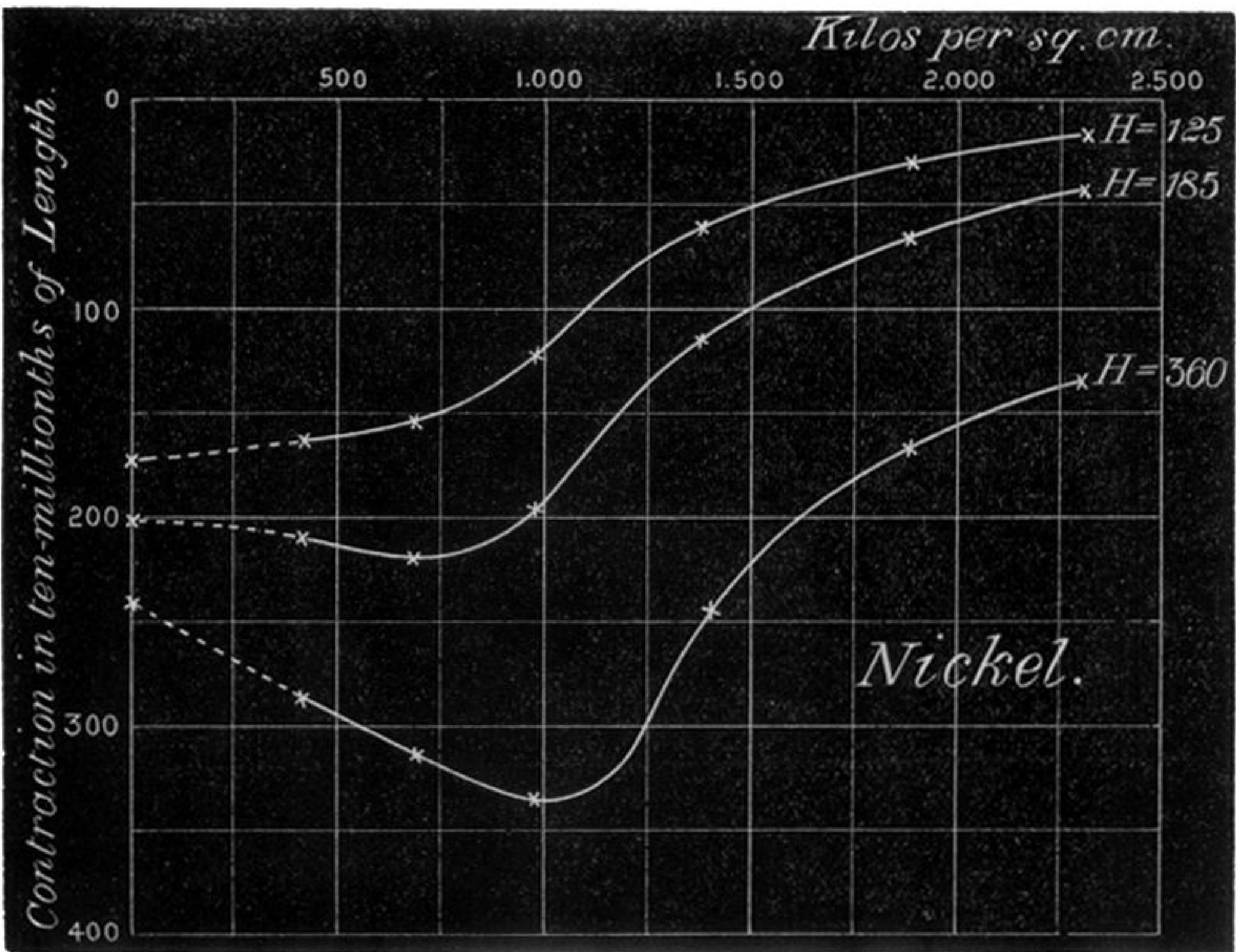
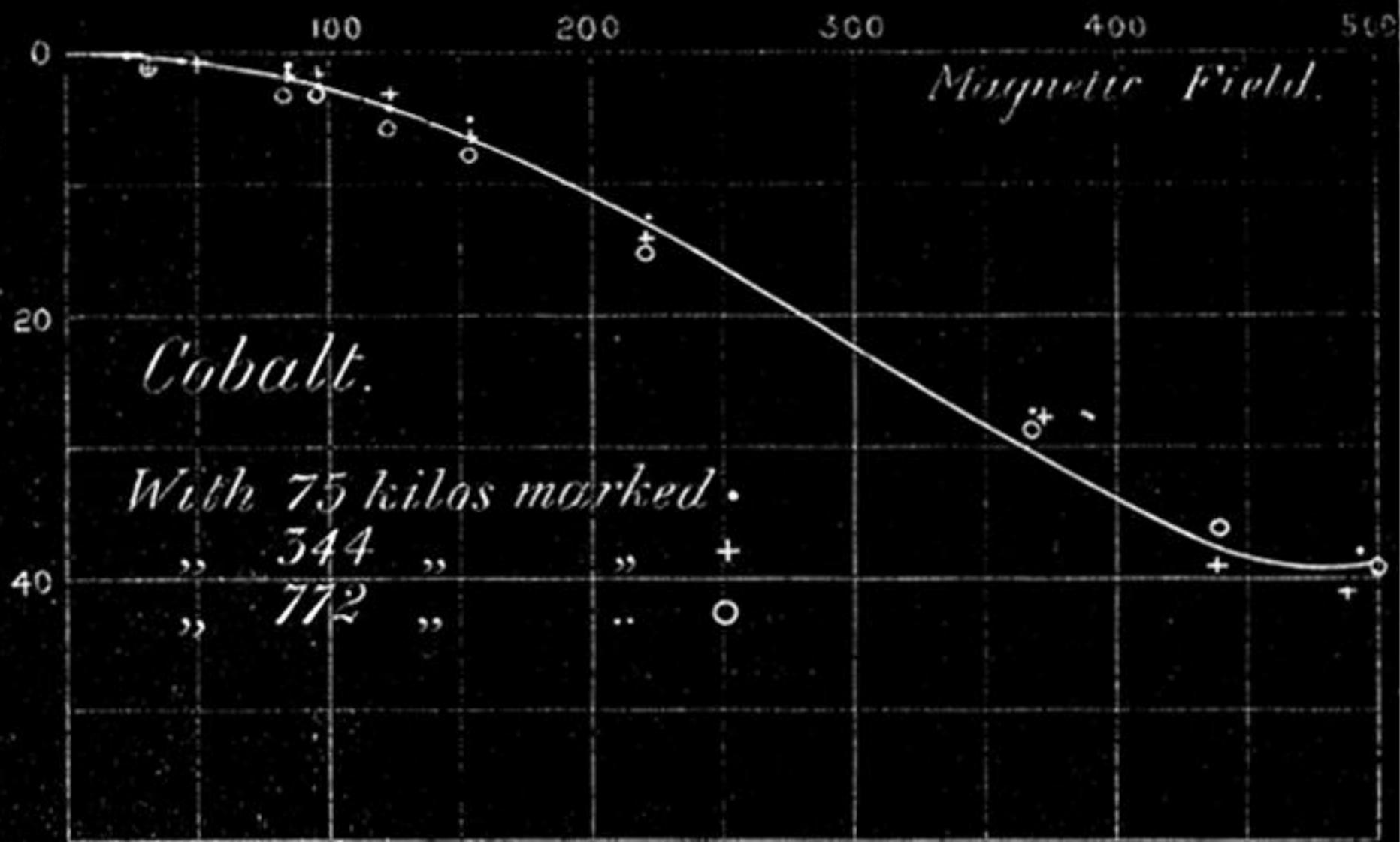


FIG. 4.



Contraction
in ten-millionths of Length.



Cobalt.

With 75 kilos marked.

,, 344 ,,

,, 772 ,,